The Role of Photonic Processed Si Surface in Architecture Engineering

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Abstract

A fast laser texturing technique has been utilized to produce micro/nano surface textures in Silicon photovoltaic cell by means of UV femtosecond laser pulses, in order to match the modern technological components to the scale, proportion, material, colour scheme and balance of buildings. The experimental evidence of the effect of femtosecond laser pulses on the spectral response of a Silicon photovoltaic cell is demonstrated and investigated. The response of this device is covering the visible to near infrared spectral region. The responsivity of the photovoltaic cell is up to 0.25A/W.

Keywords

Femtosecond Laser; Responsivitivity; Surface Modification; Nanostructures; Building Integrated Photovoltaic

Introduction

In the time when the world is debating on climate change issues which is basically due to use of fossil fuel, the use of solar energy in various form is relevant. The existing buildings are responsible for use of large amount of energy for lighting, heating, cooling and use of various energy run equipments mostly powered by fossil energy. Today's intention should be to replace this fossil fuel by solar energy which is free and available in abundance. Photovoltaic modules are in most cases still considered to be technical devices that need to be adjusted to the building skin, despite the fact that a variety of products that convert them into building components have been developed lately. However, in case the solar module becomes part of the building skin, it gains multiple functions and requires aesthetical integration into the overall design concept.

Modification of surface properties over multiple length scales plays an important role in optimizing a Material's performance for a given application. For instance, the cosmetic appearance of a surface and its absorption properties can be controlled by altering its texture [Campbell P, 1993; Semak V, *et al*, 1998] and presence of chemical impurities in the surface [Sheehy M, *et al*, 2006]. Material's susceptibility to wear and surface damage can be reduced by altering its surface chemistry, morphology, and crystal structure [Gregson V, 1984]. Also, one can consider the frictional, adhesive, and wetting forces acting at a material interface as being strongly influenced by the size and shape of the micro and nanoscale features present [Etsion I, 2005]. As such, multiscale surface modifications are a critical factor in the development of new material structures and in engineering the detailed interactions that occur at surfaces and interfaces. From the earliest work with pulsed ruby lasers, it has been understood that the unique interaction of laser light with a material can lead to permanent changes in the material's properties not easily achievable through other means. Laser irradiation has been shown to induce changes to the local chemistry, the local crystal structure, and the local morphology, all of which affect how the material behaves in a given application.

Silicon is the most commonly used semiconductor in optoelectronic devices and Silicon photodiodes are extensively used in industrial applications as reliable devices for light to electricity conversion. These features are especially important in the field of optical radiometry in which measurements of photometric and radiometric quantities have to be done with a high level accuracy. K. Al Naimee shows that the textured Silicon surface absorbs the incident light greater than the non-textured surface. The experimental evidence of the effect of nanostructure formation in Silicon photovoltaic cells on the spectral response is reported by A. M. Taleb. *et al*. The description of high accuracy interpolation of the quantum yield of Silicon photodiodes (detectors) in the near UV was reported by Kubarsepp *et al* in this reference, the results of the quantum yield calculations and of measurements obtained by using of Silicon trap detector are presented and compared. Since 1969 the amorphous Silicon plays a crucial role in producing low cost-effective solar cells. However, the photovoltaic cells made of this material tend to have lower energy

conversion efficiency than bulk silicon. Carey *et al* investigated the I-V characteristics and responsivity of photodiodes fabricated micro structured Silicon by using femtosecond laser (fs) pulses in a Sulfur containing atmosphere. Silicon surfaces irradiated with high intensity nanosecond laser pulses in the environment of Sulfur-containing gases have absorption near unity from near UV (250nm) to NIR (2500nm) at photon energies well below the band gap of ordinary Silicon, Crouch *et al*. Spontaneously developed micro structures on Silicon surfaces under the effect of short laser pulses irradiated in different ambient atmospheres have been reported in Xiaoyun. *et al*, Myers A. *et al*. The experimental results reveal that the ambient atmosphere and the laser pulse duration play key roles on the formation of microstructures. The physical processes responsible for the periodic structure formation in femtosecond laser ablation of thin films surfaces is (are) reported by G. Miyaji and K. Miyazaki, it has been found that an initial random distribution of nanoscale ablation traces is periodically structured with an increase in superimposed laser pulses. The paper presents results on the development of surface texturing by means of laser processing and investigation of the influence of laser texturizaion on the operational properties of the photovoltaic cells in order to enhance the absorption efficiency and the responsivity of the Silicon solar cells and fabrication of textured surface in Poly methylmethacrylate (PMMA).

Experimental Part

Preparation of Sample

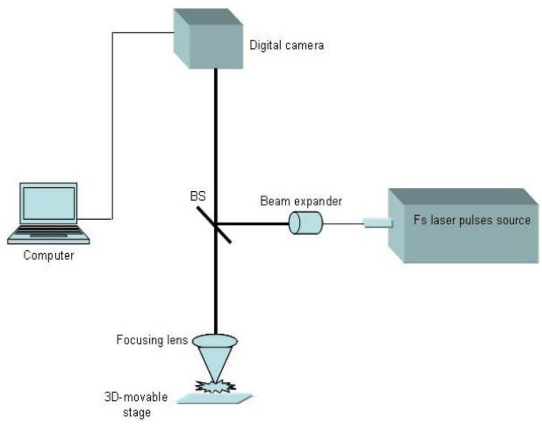

FIG.1 SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SETUP OF SAMPLES IRRADIATION

The irradiation of the photovoltaic sample was by a tunable mode-locked Ti:sapphire laser with 100fs pulse duration, 80MHz frequency at 800 nm wavelength of operation, the laser beam was attenuated by a diffractive optic attenuator and its frequency was doubled by a BBO crystal for a wavelength of 400 nm. The PMMA sample is irradiated by a CW diode laser with 0.3 watt power at 810 nm wavelength of operation. During the irradiation process a focusing objective with high numerical aperture is used in air environment. The laser beam has been expanded by a 1x4 beam expander and then focused through a 100 mm focal length lens on the target. The irradiating beam is vertically directed on the anode surface of the sample. A digital camera is used to monitor the movement of the sample during the irradiation of the cell. The setup of the samples irradiation is depicted in (FIG. 1). The irradiation process creates numerous defect sites and modifies the samples surface. A scanning Electron Microscope (SEM) images of the Si structures obtained in air environment. Line scan has been performed at a fixed scan speed.

Diffraction Pattern Achievement

In this study, the nano-ripple effect on the light diffraction in PMMA sample was achieved by transmitting a Helium Neon laser beam through a grating in the samples, and the light diffraction in Si sample was achieved by transmitting a (532nm and 600nm) laser beams through a the samples.

Responsivity Measurements

The spectral response of the samples is recorded by standard method using computerized monochromator before and after the irradiation process. The system instrumentation is controlled by a PC via the RS232 interface. The output of the monochromator is split into two output windows. One beam is directed to a calibrated detector and the other to the sample under test. During the system operation a broad band light source is passed through a monochromator signaling the desired frequency of the light illuminating the photodiode. The photovoltaic device current is measured by means of the semiconductor parameter analyzer and the results are stored on the computer. The measurements are then repeated in the (400-900) nm wavelength range.

Results and Discussion

SEM Images

A semi periodic structure is formed and observed in the range of (700-900) nm. The SEM images show a semi periodic structure known as ripples or grooves in the submicrometer range, as shown in (FIG. 2).

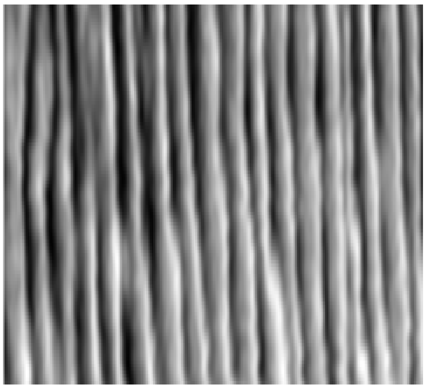

FIG. 2 THE PERIODIC STRUCTURED OF THE IRRADIATED CELL, BY A100FS LASER PULSES, 800NM WAVELENGTH, THE FIGURE SHOWS 12MM LENGTH.

Scale changing of the surface reshaping occurs even at law values of the laser irradiation. Under laser pulses, the surface becomes corrugated by nanostructured highly and valley. The spacing of these nano- channels decreases as the number of laser pulses increases and fluence. In Si photovoltaic cell the cause of formation of the nano-ripple forms is due to the optical interference of the incident and scattered laser pulses from the sample.

The reflections of the incident laser pulses from backinto the cell substrate (FIG. 3) strongly reduced the incident solar reflection and increase the absorption.

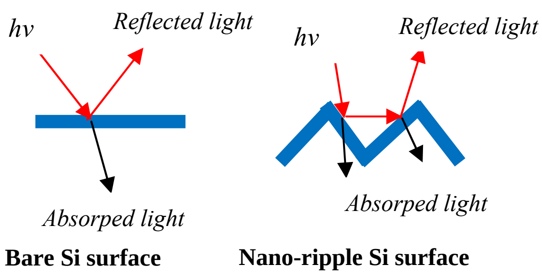

FIG.3. NANO-RIPPLE EFFECT ON THE LIGHT REFLECTION AND ABSORPTION

This method leads to the production of photovoltaic cells, indeed, with enhanced material responsivity and hence the conversion efficiency. Since the efficiency of the amorphous Silicon photovoltaic cells is increased from 7% to about 9% during the last 40 years utilizing different methods, the stepping to 14% efficiency must be by only rearranging the micro crystal structure of the cell surface.

Characterization of Diffraction Pattern

The induced of nano-ripple surface work as Diffraction Grating. (FIG. 4) shows the diffraction pattern by transmitting a Helium Neon laser beam through PMMA and reflection and diffraction from Si surface.

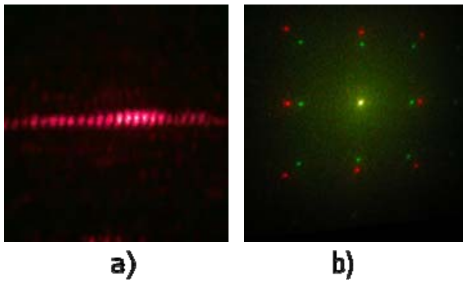

FIG. 4 GRATING DIFFRACTION PATTERN OF THE1D IRRADIATED PMMA (A) AND 2D IRRADIATED SI (B)

The change in surface scattering light intensity indicates a periodic change in optical density which may be related to the laser induced total refractive index change independent of specific molecular bond changes.

The Spectral Measurement

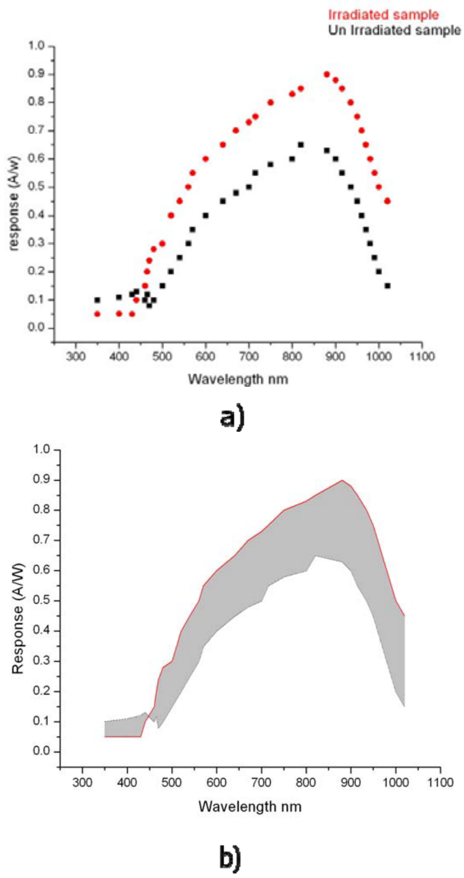

FIG. 5 SPECTRAL RESPONSE OF THE IRRADIATED AND UNIRRADIATED PHOTOVOLTAIC SOLAR CELLS (A) AND COMPARISON OF THE SPECTRAL RESPONSE CURVE OF IRRADIATED AND UNIRRADIATED CELLS (B)

The effect of the irradiation of ultrashort laser pulses on the spectral response is shown in (FIG. 5a). This figure shows the dependence of the responsivity versus wavelength and the role of the laser effects at

room temperature. The relative response increased after the irradiation processes. From this figure one can observe that the efficiency of the irradiated sample is enhanced clearly compared to unirradiated sample at wavelengths longer than 500nm. The responsivity of the photovoltaic cell hence is increased from 0.18 A/W to 0.25 A/W due to irradiation effect.

The conversion efficiency of the irradiated cell was calculated using the well known equation:

$$\eta = IV/AIo \tag{1}$$

Where I is the value of the current, V is the voltage, Io is the solar intensity and A is the solar cell area. The results show that the measured efficiency for the bare Silicon photovoltaic cell rises from 9% before irradiation to 14% after. However, the area under the response curves as shown in (FIG. 5b) indicating the total response of the irradiated samples. The ratio of the total quantum yield before and after irradiation increases by a factor 1.43 over the whole spectral range. Also the irradiation dependence on laser wavelength had been studied. The gain response curves as a function of the bias voltage for samples irradiated at different wavelengths are shown in (FIG. 6). The trend is the same at different wavelengths, 532 nm and 810 nm.

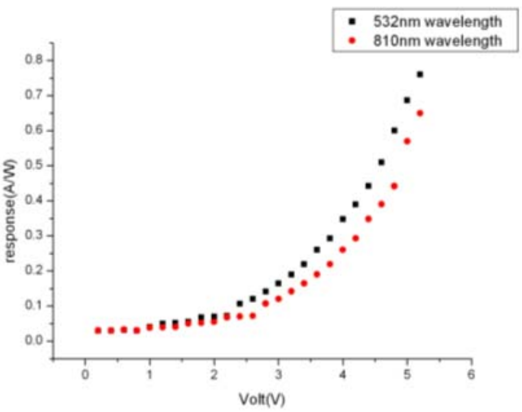

FIG. 6 THE GAIN RESPONSE OF THE IRRADIATED SAMPLE AT TWO DIFFERENT WAVELENGTHS

Overall, the integration of enhanced photovoltaic cell result in public cceptance, aesthetics and cost effectiveness.

Conclusions

In conclusion, to achieve quality in integration of photovoltaic cell into buildings we found that the use of surface textures method leads to improve the responsivity from 0.18 A/W to 0.25 A/W and the conversion efficiency of the photovoltaic cell. The irradiation process leads to the formation of Micro-Nano meter periodic structure on substrates with a large area using single or double exposition. This technique is much cheaper and simpler than the electron beam lithography. It is possible and logical to integrate photovoltaic system into the external building envelop as multifunctional elements which will in addition improve on the aesthetics.

REFERENCES

Farkas K. Façade, " Integration Typologies of Photovoltaics. Architecture and sustainable development", In: Proceedings from PLEA 2011. 27th International conference on Passive and Low Energy Architechture; 13-15 July 2011; Louvain-la-Neuve, Belgium.

Campbell P., J. Opt. Soc. Am. B 10(12) (1993).

Carey J. E., Crouch C.H., M. Shen and E. Mazur, "Visible and near-infrared responsivity of femtosecond-laser microstructured silicon photodiodes", Opt. Lett., 30 1773, (2005).

Crouch C. H., Carey J. E., J. M. Warrender, M. J. Aziz, E. Mazur and F. Y. Genin, "Comparison of structure and properties of femtosecond and nanosecond laser-structured silicon," Appl. Phys. Lett. 84, 1850, (2004).

Etsion I., Tribol J. Trans. ASME 127(1), 248 (2005).

Gregson V., Laser Material Processing (Holland Publishing Company, Holland, 1984).

Kais A. Al Naimee. Nano/Micro Surface texturing and Enhahancing of Photovoltaic Cells Efficiency by using UV Femtosecond Laser Pulse. IJAP Vol.7, (2), (2011).

Kubarsepp T., Karha P., and Ikonen E., "Interpolation of Spectral Responsivity of Silicon Photodetectors in the Near UV", Appl. Optics 39, 9–15, 39-1. (2000).

Miyaji G. and Miyazaki K., "Origin of periodicity in nanostructuring on thin film surfaces ablated with femtosecond laser pulses", Optics Express 16, 20, 16265, (2008).

Myers A., Farrell R., Karger A., Carey E. and Mazur E., "Enhancing near-infrared avalanche photodiode performance by femtosecond laser microstructuring", Appl. Opt. 45, 35, 8825, (2006).

Semak V., Dahotre N., in Lasers in Surface Engineering, Surface Engineering Series, vol. 1,ed. by N. Dahotre (ASM International, Materials Park, OH, USA,), pp. 35–67 (1998).

Sheehy M., Tull B., Friend C., Mazur E., Mat. Sci. Eng. B 137, 289 (2006).

Taleb A. M. et al, Nanostructure Formation in Silicon Photovoltaic Cells by Femtosecond Laser Pulses. Materials Science Forum Vol. 670 pp 118- 121, (2011).

Xiaoyun H., Fan, Jun, Li, Ting; Zhang, Dekai, Bai, Jintao, Hou, Xun, "Influence of preparation technique on the microscopic structure and surface morphology of nanometer TiO2 thin films", Proceedings of the SPIE, Vol. 5635, 390-398, (2005).